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## **Hydraulic Stimulation Increases Degasification Rate of Coalbeds**



**UNITED STATES DEPARTMENT OF THE INTERIOR**

# **Hydraulic Stimulation Increases Degasification Rate of Coalbeds**

**By C. H. Elder and Maurice Deul**

**Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.**



**UNITED STATES DEPARTMENT OF THE INTERIOR**

**Rogers C. B. Morton, Secretary**

**Jack W. Carlson, Assistant Secretary—Energy and Minerals**

**BUREAU OF MINES**

**Thomas V. Falkie, Director**

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# HYDRAULIC STIMULATION INCREASES DEGASIFICATION RATE OF COALBEDS

by

C. H. Elder<sup>1</sup> and Maurice Deul<sup>2</sup>

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## ABSTRACT

Coal degasification boreholes drilled from the surface have been successfully hydraulically stimulated to increase the flow of gas from the coal. This Bureau of Mines report describes the hydraulic stimulation procedure for a coalbed, the equipment required, and design criteria for the treatment. Three examples of stimulation treatment show from fivefold to twentyfold increases in gas production. The tests were conducted in the Pocahontas No. 3 coalbed, Buchanan County, Va., the Pittsburgh coalbed, Washington County, Pa., and the Mary Lee coalbed, Jefferson County, Ala. Two sites where the coal was hydraulically stimulated and exposed by subsequent mining show no adverse effect on mining operations through the treated zones. The induced vertical partings were confined to the coalbed and did not in any way affect either roof or floor rock.

## INTRODUCTION

Drilling degasification holes into the coalbed in advance of mining is one method to reduce the formation pressure and to remove a large volume of the contained methane. Gasflow into a borehole is dependent upon coalbed permeability and formation pressure. A greater rate of degasification can be achieved by increasing coalbed permeability in the drainage area and by increasing the surface area exposed for more rapid desorption. Hydraulic stimulation of a coalbed is designed to accomplish this.

Twelve test degasification boreholes drilled into coalbeds have been hydraulically stimulated. Production has increased in these treated boreholes from fivefold to twentyfold. These preliminary production results show that this is a valuable stimulation technique and warrants further development.

This Bureau of Mines report describes the hydraulic stimulation procedure and gives examples of the application of this technique in three coalbeds.

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<sup>1</sup>Geologist.

<sup>2</sup>Research supervisor.

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## DESCRIPTION OF HYDRAULIC STIMULATION

Hydraulic stimulation increases fluid flow by inducing or extending a vertical parting in a selected section of a formation or coalbed by applying hydraulic pressure with controlled injection of gelled water. The parting achieved in this way is extended several hundred feet into the coalbed by continued pumping of a large volume of the treatment fluid. The length of induced parting depends upon the injection rate, formation strength characteristics, volume of treatment fluid, and the flow characteristics of the fluid. Sized particles, such as sieved sand, added to the gelled fluid are carried into the induced parting and serve as a propping agent to hold the parting open after the applied hydraulic pressure is released. The propped parting provides a highly permeable path to the borehole. The hydraulic fluid is water-gelled with a natural gum and contains chemical additives that cause the gel to break down and revert to a fluid of water viscosity after a few hours. This allows for the removal of the fluid from the induced parting and the borehole after stimulation treatment. The borehole is cleared of excess sand and treatment fluid and put on production for degasification of the coalbed.

The hydraulically induced parting should be contained within the coalbed, and its orientation should be vertical and may follow the direction of the major cleat or joints. Hubbert and Willis (9)<sup>3</sup> state that hydraulically induced fractures should form approximately perpendicular to the least principal stress and that in tectonically relaxed areas the least stress will be approximately horizontal; therefore, the fracture would be oriented vertically. They state further that not only will the fractures be vertical, but they also should have roughly the same direction of strike in all boreholes treated within the immediate area. Fraser and Pettit (6), from a field test in the Howard Glasscock field in Howard County, Tex., where impression packer tests were run, concluded that the fractures are vertical even at very shallow depths and that the theoretical relationships between tectonic stress conditions, fracture type, and orientation are valid in their test area. Daneshy (3) deduces from his study that in practice, the well bore may contain discontinuities in the form of preexisting cracks (cleat and joints in coal) and bedding planes, that such features will locally change the stress distribution in their vicinity, and that they are likely placed for fracture orientation. Harrison and Kieschnick (8) from their studies that where a consolidated sand is bounded by nonbrittle shales the vertical extent of the fractures would be limited by the shales; in west Texas relatively low horizontal compressive stresses and already existing fractures offered relatively little resistance to fracture induction and extension.

## EQUIPMENT

The equipment for hydraulic stimulation consists of truck-mounted high-pressure positive-displacement injection pumps, gelled water, a storage tank, and a truck-mounted blender and sand proportioner.

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<sup>3</sup>Underlined numbers in parentheses refer to the list of references at the end of this report.

A typical pump unit is capable of delivering 1,000 hydraulic hp with up to 42 bbl/min injection rate at high pressure, although the burst pressure of casing or tubing is never exceeded.

The blending equipment consists of booster pumps, semiautomatic proportioners, and a jet blender for inline mixing of gelled fracturing fluid, chemical additives, and a propping agent at the volume capacity matching the pump unit. A storage tank for water and fracture fluid equal to the batch volume of the hydraulic stimulation treatment is placed on site at a location convenient to the pumping, blending units, and the borehole. A hopper truck is used for carrying and dispersing the propping agent (10- to 20-mesh sand) to the proportioner and jet blender for the fracture treatment.

Recording flow and pressure meters are used to monitor the mixing of chemicals and propping agent, injection rate, and wellhead pressures to provide control during the fracture stimulation treatment.

#### HYDRAULIC STIMULATION TREATMENT DESIGN

Procedures in "The Fracbook Design/Data Manual" (7) of Halliburton Services, Duncan, Okla., were used to select a hydraulic treatment design. The procedures incorporate borehole and formation factors, engineering theory, and results of case studies in preparing an effective fracture plan.

The following criteria are used in developing a stimulation treatment design:

Injection rate	bbl/min
Assumed fracture height	feet (coalbed thickness)
Net formation thickness	feet (coalbed thickness)
Young's elastic modulus	lb/in <sup>2</sup>
Formation permeability	md
Formation porosity	pct
Bottom hole treatment pressure	lb/in <sup>2</sup>
Reservoir pressure	lb/in <sup>2</sup>
Fluid loss coefficient	ft/min <sup>1/2</sup>
Spurt loss coefficient	gal/ft <sup>2</sup>
Type of gel	
Gel concentration	lb/1,000 gal
Well spacing	acreage
Drainage radius	ft
Well bore radius	ft
Damage ratio	
Flow behavior index	
Fracture fluid consistency index	
Type and concentration of propping agent	mesh size-sand lb/gal average

The values for the design criteria are used in calculating created fracture length, length of propped fracture, height of proper fracture, amount of propping agent required, and expected production increase for various volumes of treatment. From these calculated results the best treatment plan is selected.

An injection rate of 10 bbl/min was selected for relatively thin coalbeds to contain the propagated fracture within the coalbed. A greater injection rate should tend to create higher fracture heights. A lower injection rate could have so low a fluid velocity that the propping sand could settle out, plug the created fracture, and effectively stop the hydraulic fracture stimulation procedure.

A volume of fracture fluid or pad is pumped into the formation to initiate and condition the fracture before the propping agent is added. The volume used is determined from evaluation of formation factors. Formation factors such as coalbed thickness, porosity, permeability, and formation pressure were obtained from exploratory core hole drilling records and test results obtained during the drilling of the degasification boreholes. Gas pressures in the coalbed were measured by bottom-hole pressure buildup tests. Permeability was calculated from the bottom-hole pressure buildup curves and gas and/or water production data obtained during drill stem test (dst). Porosity of the coalbed was obtained from laboratory tests and from estimates of inplace porosity related to the joint or cleat spacing of the coalbed as observed in nearby mines and from core samples. A value of  $0.3 \times 10^6$  for Young's modulus of elasticity was used for coal in the design (5).

Other design criteria relating to fluid properties and flow properties were obtained from tables and charts in the Fracbook (7), developed by experimental research in Halliburton's laboratory. The Halliburton Services computer was used in calculations for design of each treatment program.

#### EXAMPLES

Three hydraulic stimulation treatments have been successfully completed in the Pocahontas No. 3 coalbed, Buchanan County, Va., the Mary Lee coalbed, Jefferson County, Ala., and the Pittsburgh coalbed, Washington County, Pa.

##### Pocahontas No. 3 Coalbed, Buchanan County, Va. (2)

A test hole was drilled into a projected barrier pillar in an area not to be mined for several years. The test site is in central Buchanan County, Va. The hole penetrated a series of Pennsylvanian sandstones, shales, and coals to test the gassy Pocahontas No. 3 coalbed. The 1,530-foot-deep hole was logged with a gamma ray-density logging tool to obtain geophysical data on formation density, porosity, and lithology (fig. 1). The 8-inch-diameter hole was cased with 4.5-inch steel casing from the surface to the top of the coalbed, and the casing was pressure-cemented.

Monitoring equipment consisting of a flowmeter and pressure gages was installed. Waterflow was measured at 1.3 gal/hr. The inflowing water inhibited the flow of gas and required frequent swabbing to maintain a gasflow. The borehole flowed gas at 600 ft<sup>3</sup>/d with continued swabbing to rid the hole of water.

In July 1970, a hydraulic stimulation procedure designed by the Bureau of Mines was attempted. The coalbed was treated successfully with a thickened



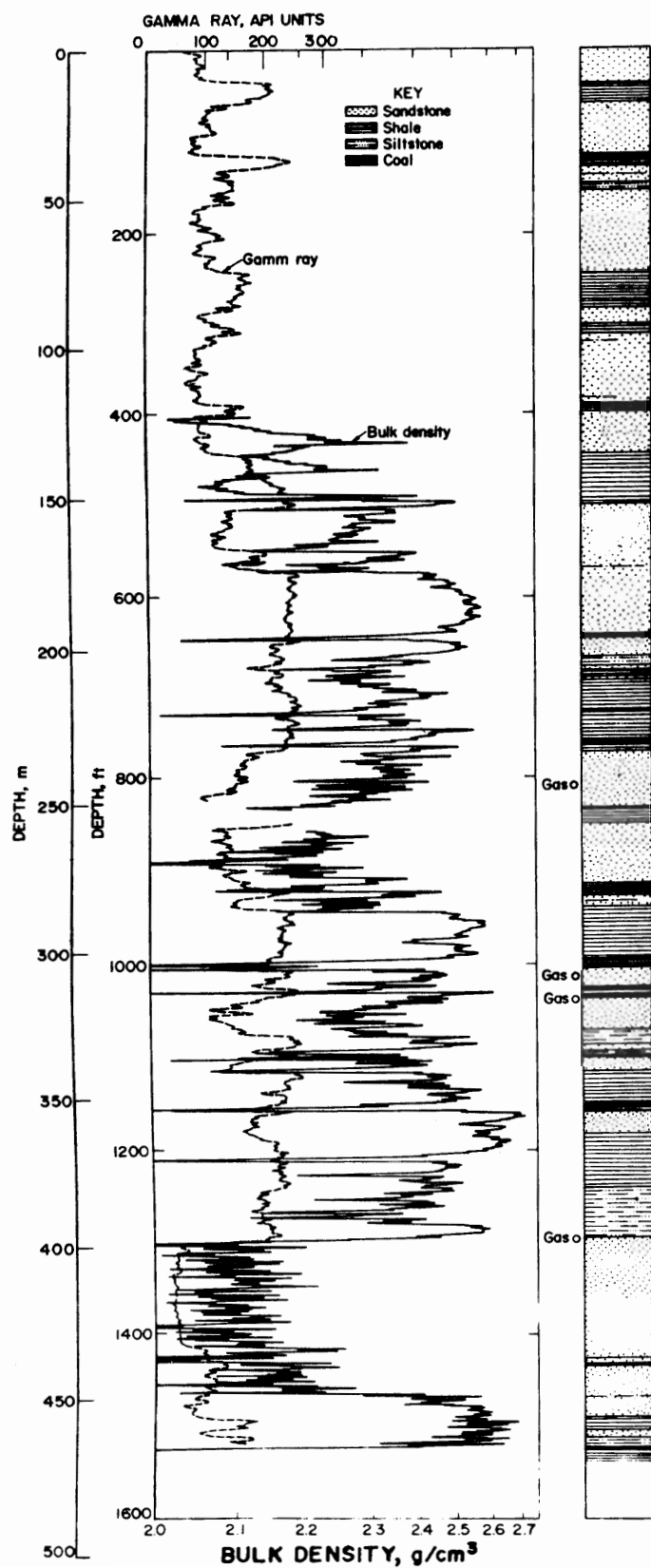


FIGURE 1. - Lithology, gamma ray, and density log of strata overlying the Pocahontas No. 3 coalbed, Buchanan County, Va.

water-base fracturing fluid containing 10- to 20-mesh sand as a propping agent (fig. 2). The initial fracture in the coalbed occurred at 3,200 lb/in<sup>2</sup>. The fractures were propagated into the coalbed with 2,400 to 3,450 lb/in<sup>2</sup> pump pressure at an average injection rate of 10 bbl/min of gelled-water fracturing fluid. Fourteen thousand eight hundred gallons of fracturing fluid and 4,000 lb of 10- to 20-mesh propping sand were injected into the induced fractures in the coalbed. The high initial fracture at 3,200 lb/in<sup>2</sup> is caused by complex residual tectonic forces in the area of the test hole (9).

An additional factor for the high break pressure may be due to borehole damage. Cervik and Cetinbas (1), in research on water infusion for methane control, experienced difficulty infusing the friable Pocahontas No. 3 coalbed through a horizontal hole drilled into the coalbed from mine workings. An experiment was conducted to determine if a zone of reduced permeability surrounded the horizontal borehole. A 1-inch-pipe was grouted to a depth of 195 feet in a 200-foot hole. Gasflow rate from this 5 feet of hole was 300 ft<sup>3</sup>/d. The hole was fractured with water. Break occurred at 1,200 lb/in<sup>2</sup> followed by an abrupt drop in pressure (fig. 3); a secondary fracture occurred shortly afterwards. Water injection rate during treatment was 15 gal/min, the maximum capacity of the pump. Gasflow after treatment about a month later was 13,000 ft<sup>3</sup>/d.

After stimulation treatment of the vertical borehole, the hole was swabbed to remove water and gasflow was monitored. On the first day, waterflow decreased from 120 to 20 gal/hr. Gasflow increased from 2,500 to 3,500 ft<sup>3</sup>/d (stp) as water was drained from the expanding drainage radius. During the second day waterflow averaged 15 gal/hr but flowed in surges; the

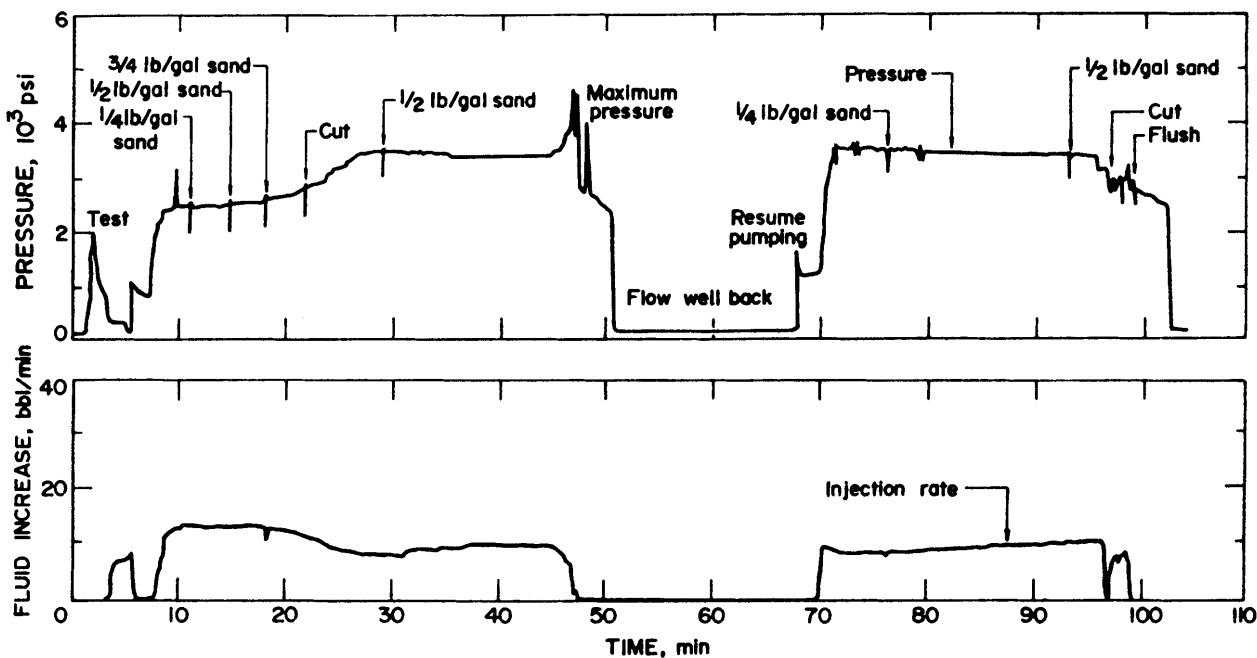


FIGURE 2. - Wellhead pressure and injection rate charts of hydraulic stimulation treatment of Pocahontas No. 3 coalbed.

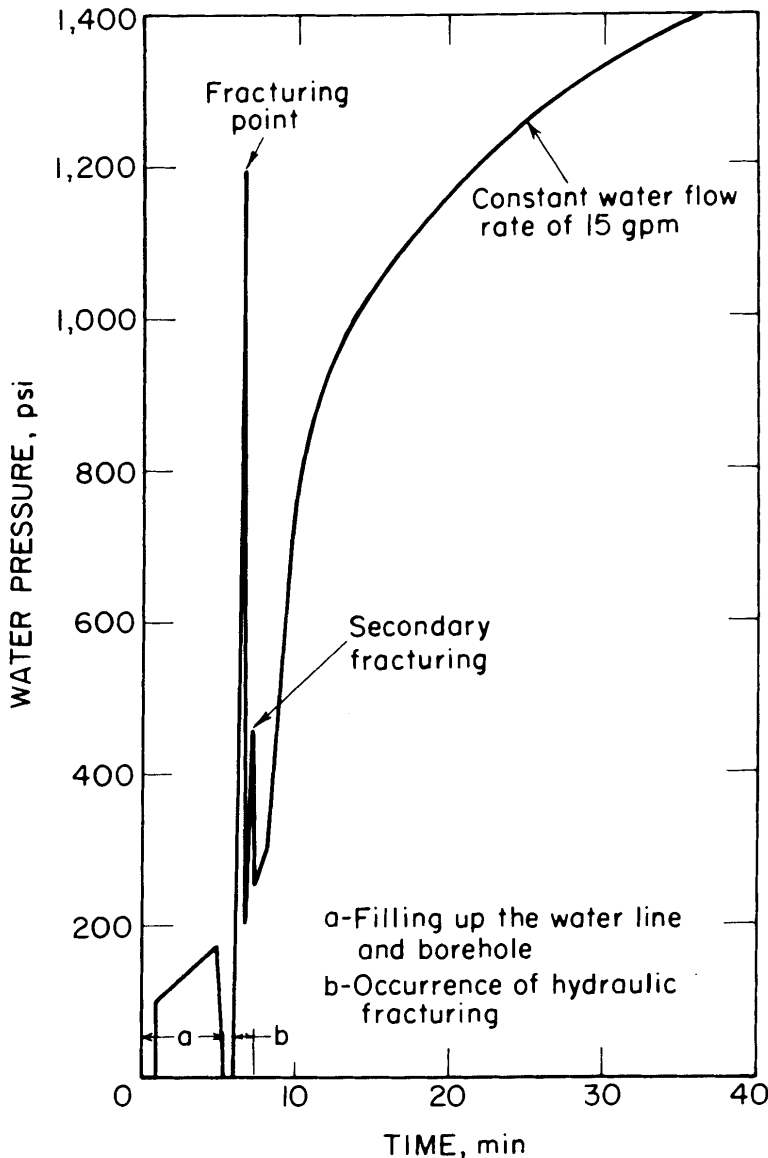


FIGURE 3. - Hydrofrac of horizontal hole in Pocahontas No. 3 coalbed.

gasflow increased from 3,500 to 9,900 ft<sup>3</sup>/d (stp). The fourth day, gasflow rates increased to 12,000 ft<sup>3</sup>/d (stp), while the waterflow rate decreased, flowing an average of 10 gal/hr during flow periods, but with a longer flow-nonflow cycle. On the fifth day gasflow stabilized, averaging 12,000 ft<sup>3</sup>/d (stp), while the waterflow rate continued to decline to 2.9 gal/hr flowing in cycles of 12 hours of nonflow (fig. 4).

The twentyfold increase in gasflow was, indeed, encouraging. It was evident, however, that a pumping or swabbing service must be provided to remove the water inflow to maintain stable gas production.

Mary Lee Coalbed,  
Jefferson County,  
Ala.

A test site was located in section 23, T 18S, R 6 W near Oak Grove, Jefferson County, Ala., for experimental degasification of the Mary Lee coalbed in advance of mining (4). Five holes (1,081 to 1,093 feet total depth) were drilled in a

pattern on a structural nose on the flank of the Sequatchie anticline. The holes penetrate Pennsylvanian sandstones, shales, and coalbeds (fig. 5). Drilling was completed in July 1971. Hole 3 SW was drilled to the top of the coalbed at a 1,075-foot depth and cased with 7-inch steel casing. After casing the hole, 5 feet of coalbed was cored and the borehole was put on production. Gas production was low at the start but increased as the coalbed was dewatered. The maximum production was from borehole 3 SW. After 16 months, production from this hole had reached an average of 5,000 ft<sup>3</sup>/d gas with 6 bbl/d water. A stimulation treatment was then planned to test the effectiveness of stimulation of this coalbed to increase the degasification rate.

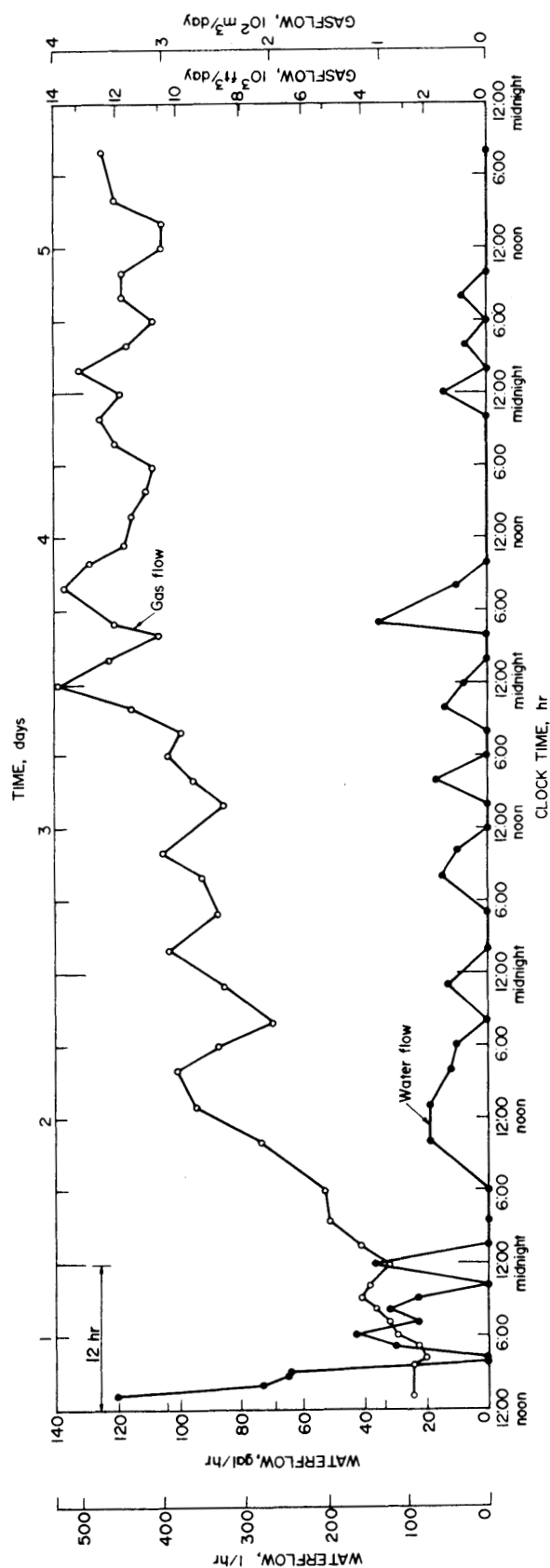


FIGURE 4. - Gas and water production rates following hydraulic stimulation treatment of Pocahontas No. 3 coalbed.

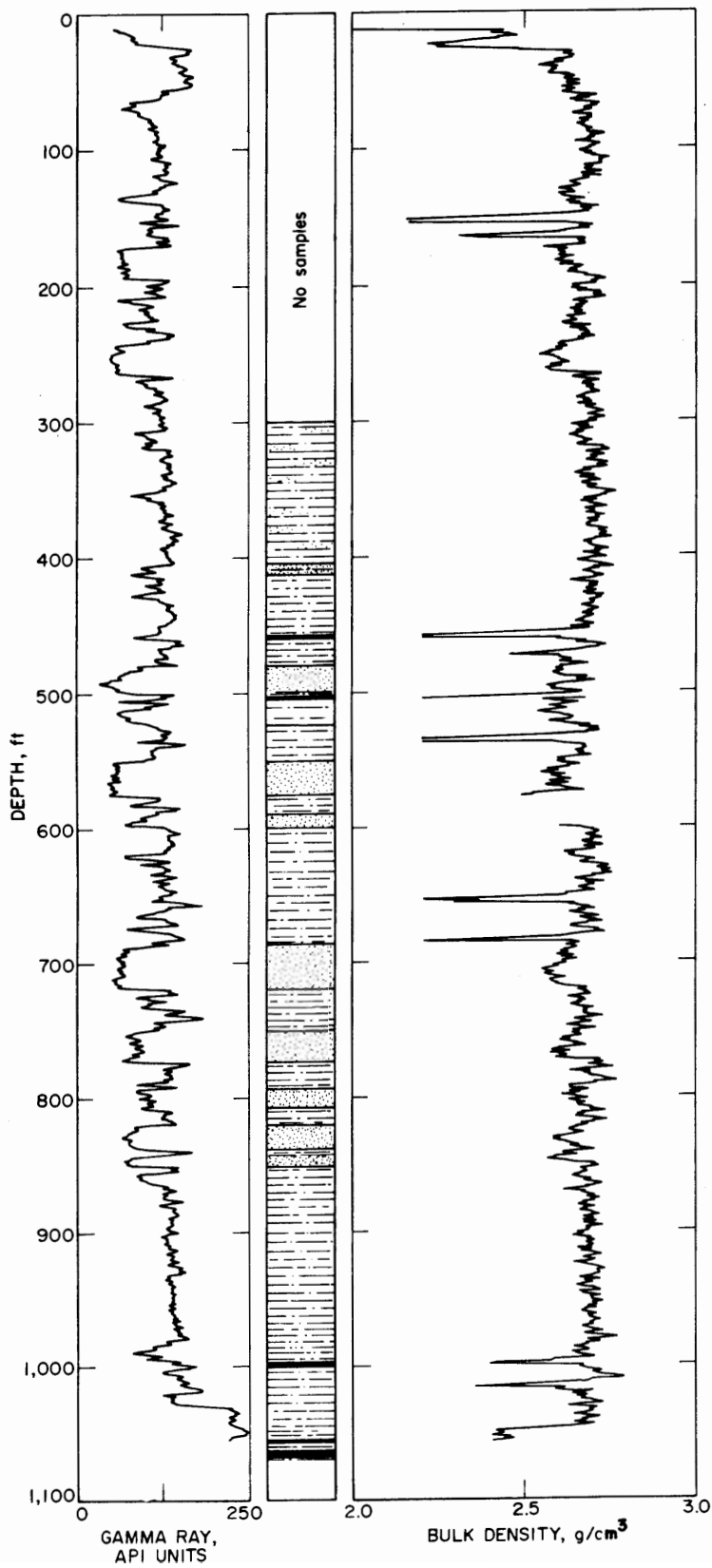


FIGURE 5. - Lithology, gamma ray, and density log of strata overlying the Mary Lee coalbed, Jefferson County, Ala.

A hydraulic stimulation treatment program was prepared with the aid of a design plan of Halliburton Services. Design 2 from a computer calculation (tables 1 and 2) selected for the treatment plan provided for 10,000 gal of gelled water, with a 2,500-gal water pad to be injected into the coal at 10 bbl/min to propagate a fracture or parting. Six thousand pounds of 10- to 20-mesh sand were mixed with the fracture fluid at the rate of 3/4 lb/gal to serve as a propping agent in the induced fracture after treatment.

TABLE 1. - Hydraulic fracture stimulation plan, site 1, hole 3 SW, Jefferson County, Ala.

Design No.	Production increase	Volume, 1,000/gal		Propped fracture, feet		Viscosity cp	Fracture, width inch	Prop sand, sacks	Created fracture length, feet
		Total	Pad	Length	Height				
1.....	7.5	5.0	2.5	105	5.2	6	0.207	19	233
2.....	11.7	10	2.5	255	5.5	7	.242	56	758
3.....	15.6	15	2.5	377	5.6	7	.266	94	1,040
4.....	19.4	20	2.5	437	5.7	7	.234	131	1,007

Source: Computer computation from Halliburton Services.

TABLE 2. - Criteria used in computation of hydraulic fracture stimulation plan (7), site 1, hole 3 SW, Jefferson County, Ala.

Injection rate.....	bbl/min..	10.0
Assumed fracture height.....	ft..	7.0
Net formation thickness.....	ft..	5.0
Plastic modulus.....	lb/in <sup>2</sup> ..	0.30 × 10 <sup>6</sup>
Formation permeability.....	md..	5.0
Formation porosity.....	pct..	0.04
Bottom hole treatment pressure.....	lb/in <sup>2</sup> ..	2,050.0
Reservoir pressure.....	lb/in <sup>2</sup> ..	390.0
Reservoir fluid vis.....	cp..	0.02
CW--Fluid loss coef.....	ft/min <sup>1/2</sup> ..	0.00310
Spurt loss.....	gal/ft <sup>2</sup> ..	0.21
Type of gel (Halliburton).....		WG-6
Gel concentration.....	lb/1,000 gal..	20.0
n'-Prime.....		0.728
k'-Prime (slot).....	lb <sub>f</sub> -sec <sup>n</sup> /ft <sup>2</sup> ..	0.000698
Well spacing.....	acres..	30.0
Drainage radius.....	ft..	563.0
Wellbore radius.....	ft..	0.25
Damage ratio.....		3.0
Type and conc prop sand (8-12-mesh).....	lb/gal avg..	0.75

The treatment was done through 2-7/8-inch high-pressure tubing with a tension packer in the string set at 988 feet in the 7-inch casing. The bottom of the tubing was at the midpoint of the coalbed.

The initial fracture of the coal occurred at 800 lb/in<sup>2</sup> gage. The fracture was extended into the coalbed at 1,100 to 1,200 lb/in<sup>2</sup> pumping pressure and a steady 10 bbl/min injection rate. Ten thousand gallons of gelled water and 6,000 lb of 10- to 20-mesh propping sand were pumped into the coalbed during propagation of the fracture (fig. 6). After treatment, the borehole was swabbed free of water, and 30 feet of sand fillup was cleared from the borehole. After the water pump was installed, the borehole was returned to production. All fracturing fluid was recovered.

The gasflow increased after treatment from 5,000 ft<sup>3</sup>/d to a maximum rate of 90,000 ft<sup>3</sup>/d in 11 days (fig. 7). During the next 7 months a normal decline in flow occurred. The flow rate stabilized at 50,000 ft<sup>3</sup>/d. The actual tenfold production is very close to the calculated production increase of 11.7-fold.

Pittsburgh coalbed, Washington County, Pa.

A test site was located near Lone Pine, Washington County, Pa., for experimental degasification of the Pittsburgh coalbed in advance of mining. Four holes 405 to 552 feet in depth were drilled in a pattern on the flank of the Amity anticline. The holes penetrated Pennsylvanian sandstones,

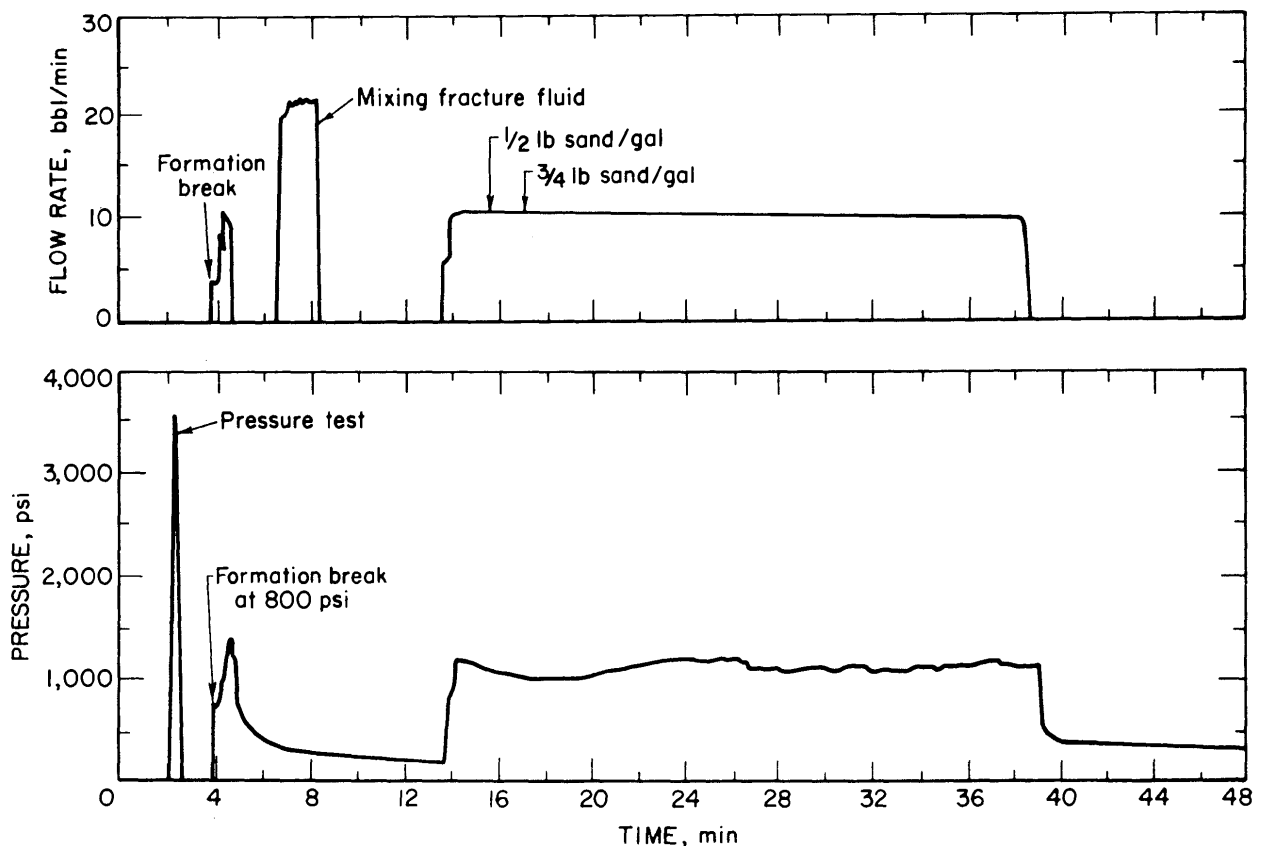


FIGURE 6. - Wellhead pressure and injection rate charts of hydraulic stimulation of Mary Lee coalbed.

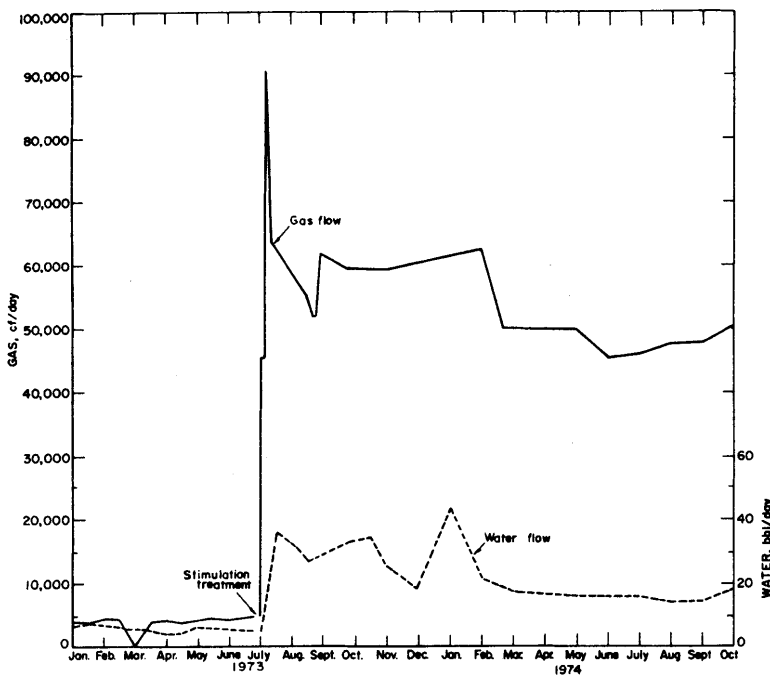


FIGURE 7. - Gas and water production rates before and after hydraulic stimulation treatment of Mary Lee coalbed.

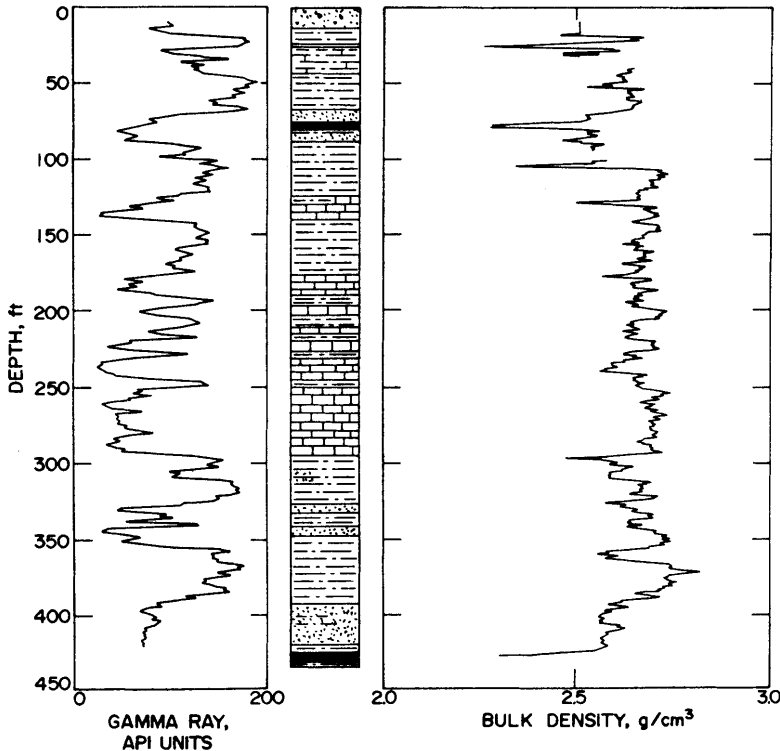


FIGURE 8. - Lithology, gamma ray, and density logs of strata overlying the Pittsburgh coalbed, Washington County, Pa.

shales, limestones, and coal-bed (fig. 8). Nine-inch-diameter holes were drilled near the top of the coalbed and cased with 7-inch steel casing. After the holes were cased, the 7-foot coalbed was cored and the boreholes put on production. Initial gas production beginning in June 1972 was low but increased as the coalbed was dewatered. After 18 months, gas production from borehole 1 NE stabilized at an average of 7,000 ft<sup>3</sup>/d with 4-1/4 bbl/d of water. This borehole was fracture-treated to improve degasification rate and test the effectiveness of stimulation of the Pittsburgh coalbed.

The hydraulic stimulation treatment program was prepared utilizing a design plan of Halliburton Services. Design 2 from the computer output, selected for the treatment plan (tables 3 and 4), provides for 10,000 gal of gelled water with a 1,600-gal water pad to be injected into the coal of 10 bbl/min. Six thousand pounds of 10- to 20-mesh sand were mixed with fracture fluid at the rate of 1/2 to 3/4 lb/gal to serve as a propping agent in the induced fracture.

The treatment was done through 2-7/8-inch high-pressure tubing with a tension packer in the string set at 412 feet in the 7-inch casing.



TABLE 3. - Hydraulic fracture stimulation plan, site 3, hole 1 NE, Washington County, Pa.

Design No.	Production increase	Volume, 1,000/gal		Propped fracture, feet		Viscosity cp	Fracture, width inch	Prop sand, sacks	Created fracture length, feet
		Total	Pad	Length	Height				
1.....	9.2	5.0	1.0	165	4.9	4	0.221	30	397
2.....	13.2	10	1	309	5.2	4	.253	68	862
3.....	15.2	15	1	433	5.3	5	.273	105	907
4.....	19.4	20	1	547	5.4	5	.289	143	1,133

Source: Computer computation from Halliburton Services.

TABLE 4. - Criteria used in computation of hydraulic fracture stimulation plan (7), site 3, hole 1 NE, Washington County, Pa.

Injection rate.....	bb1/min..	10.0
Assumed fracture height.....	ft..	7.0
Net formation thickness.....	ft..	6.0
Elastic modulus.....	lb/in <sup>2</sup> ..	0.30 × 10 <sup>6</sup>
Formation permeability.....	md..	5.0
Formation porosity.....	pct..	0.04
Bottom hole treatment pressure.....	lb/in <sup>2</sup> ..	722.0
Reservoir pressure.....	lb/in <sup>2</sup> ..	166.0
Reservoir fluid vis.....	cp..	0.02
CW--Fluid loss coef.....	ft/min <sup>1/2</sup> ..	0.0031
Spurt loss.....	gal/ft <sup>2</sup> ..	0.21
Type of gel (Halliburton).....		WG-6
Gel concentration.....	lb/1,000 gal..	20.0
n'-Prime.....		0.728
k'-Prime (slot).....	lb <sub>f</sub> -sec <sup>n</sup> /ft <sup>2</sup> ..	0.000898
Well spacing.....	acres..	30.0
Drainage radius.....	ft..	563.0
Wellbore radius.....	ft..	0.25
Damage ratio.....		3.0
Type and conc prop sand (10-20-mesh sand).....	lb/gal avg..	0.75

The initial fracture of the coal was achieved at 500 lb/in<sup>2</sup> gage. The fracture was extended into the coalbed at 1,200 to 1,400 lb/in<sup>2</sup> pumping pressure and a steady 11.4-bbl/min injection rate. Ten thousand two hundred and thirty gallons of gelled water and 6,000 lb of 10- to 20-mesh propping sand were pumped into the coalbed during propagation of fracture (fig. 9). Midway through the pumping, the formation plugged. The system was allowed to back-flow to clear the blockage and the treatment was completed. After treatment the borehole was swabbed free of water, and a few feet of sand accumulation was cleaned from the borehole. With reinstallation of the water pump, the borehole was returned to production. All fracturing fluid was recovered.

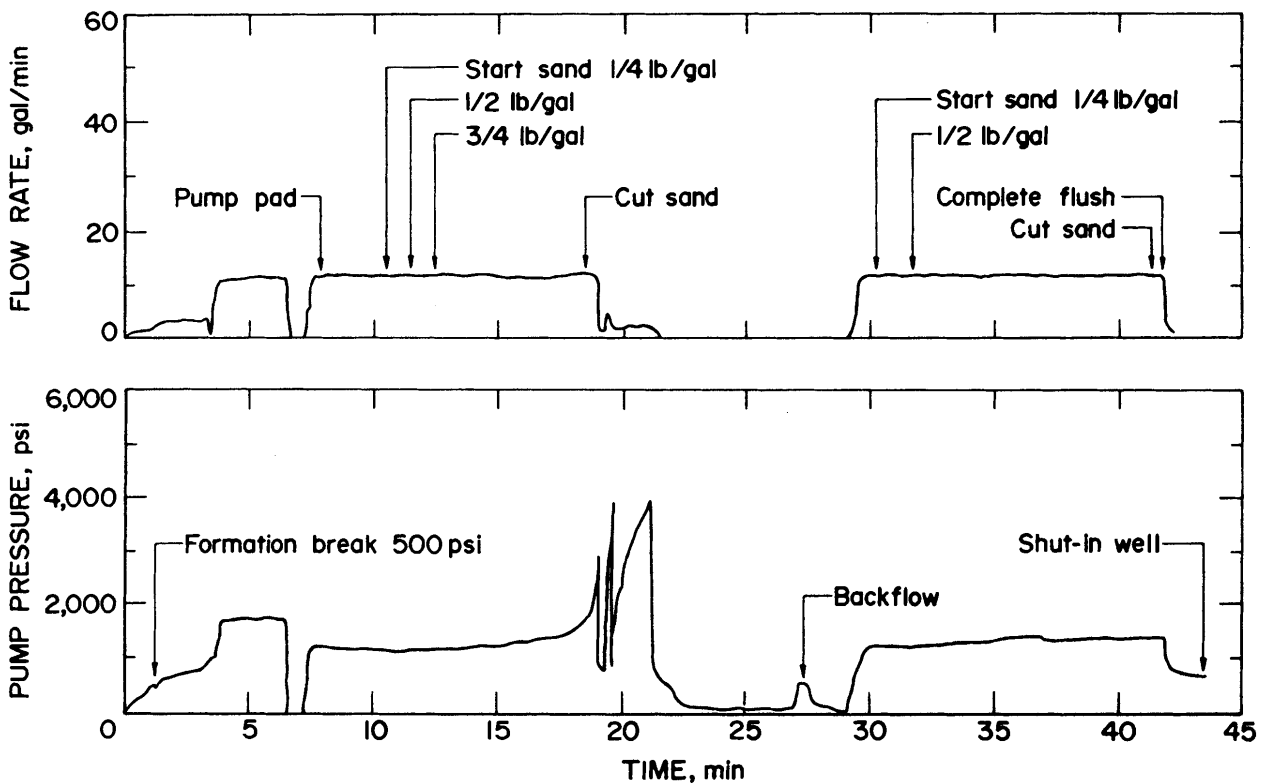


FIGURE 9. - Wellhead pressure and injection rate charts of hydraulic stimulation treatment of Pittsburgh coalbed.

The gasflow increased after treatment from an average of 7,000 ft<sup>3</sup>/d to a rate of 35,750 ft<sup>3</sup>/d in 3-1/2 months. Gas production had not stabilized (fig. 10).

#### OBSERVED INDUCED FRACTURES IN COALBEDS

The No. 6 coalbed in Jefferson County, Ill., was hydraulically stimulated in a degasification borehole about 1,500 feet in advance of mining. The stimulation design provided for the injection of 12,000 gal of fracturing fluid and 6,400 lb of 10- to 20-mesh propping sand. The induced fracture was observed in the coalbed where it intercepted development entries in the mine. The sand-propped fracture occurred in the upper part of the coalbed, extending from the roof to a 3-inch shale parting 22 inches above the floor. The induced fracture was mapped for 416 feet from the borehole striking in a direction of N 76° E. The fracture was a single vertical plane, 1/8 to 1/4 inch wide, and 7 feet high. It was filled with propping sand from the roof to a shale parting 22 inches above the floor of the coalbed. A hairline crack in the roof was exposed where the continuous miner removed a small area of head coal. The head coal generally is left in place during mining for roof control. The crack extended a few inches into the roof rock. It did not contain sand or fluid. The roof rock was dry and sound across the crack and showed no offset or weakness. Production data on stimulation effect for this test site showed an increase from initial production of 100 to 200 ft<sup>3</sup>/d to 4,300 ft<sup>3</sup>/d.

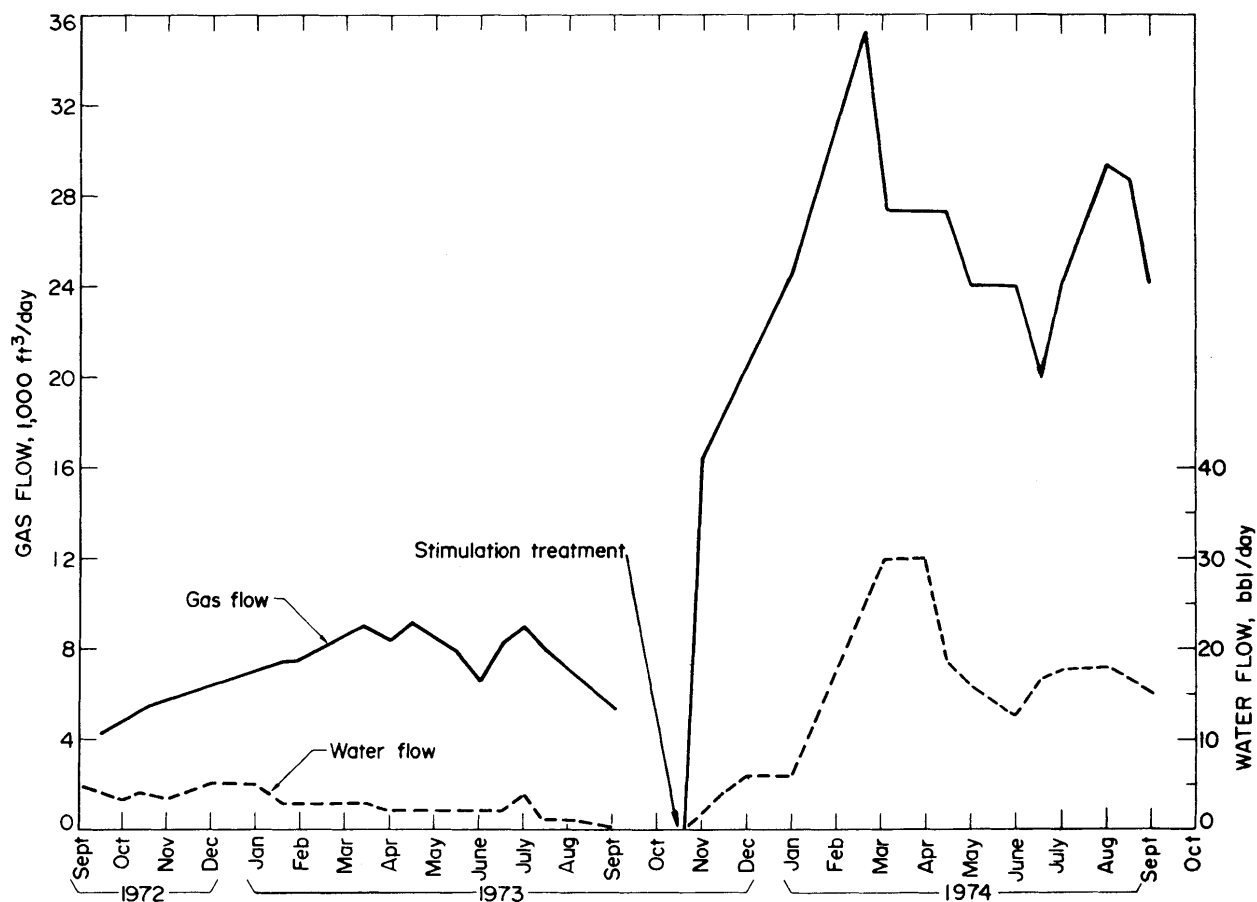


FIGURE 10. - Gas and water production rates before and after hydraulic stimulation treatment of Pittsburgh coalbed.

A test hole in the Pittsburgh coalbed in Washington County, Pa., was drilled 500 feet in advance of mining and hydraulically stimulated to specifically observe the effect of fracturing. The induced fractures were exposed during mining; they were vertical, extending from roof rock to floor rock. There is no evidence of fractures extending into the roof or floor rock of the mine, and the roof and floor of the mine were dry and sound. The induced fractures within a few feet of the test hole ranged from 1/8 to 2-1/2 inches in width and were filled with 10- to 20-mesh propping sand from floor to roof. The fractures were propagated along the butt and face cleat directions in the coalbed. The total length of the induced fractures had not been exposed by mining at the time of this writing.

#### DISCUSSION AND CONCLUSIONS

Coalbeds can be successfully hydraulically stimulated from a borehole to increase the rates of gas production. The gas production rate after stimulation shows an increase of from fivefold to twentyfold over the production rate before stimulation.

A vertical induced fracture is expected in the coalbed due to the strong jointed character of the coalbed and also due to the fact that the injection pressures are normally too low to lift the overburden for a horizontal fracture.

Impression packers have shown that vertical fractures were created perpendicular to the least in situ pressure in the formation; generally their direction is affected by major joints in the formation.

Vertical induced fractures observed in the No. 6 coalbed of Illinois and the Pittsburgh coalbed of Pennsylvania were contained within the coalbed. No adverse effect or extension of the induced fractures into the roof or floor rock of the mine was evident. The width and length of the induced fractures observed in coalbeds correlate closely to the calculated values in the treatment designs. From these observations, it is evident that hydraulic stimulation treatments can be designed to increase degasification rates from a coalbed without creating hazardous conditions for mining.

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